RL-TR-88-316, Updated
Final Technical Report
September 1994

GRAPHICAL AIDS FOR THE USERS OF GEMACS (GAUGE): RAY TRACING ENHANCEMENTS

Decision-Science Applications, Inc.

Jeffrey A. Evans and Edgar L. Coffey

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

Rome Laboratory
Air Force Materiel Command
Griffiss Air Force Base, New York

This report has been reviewed by the Rome Laboratory Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

RL-TR-88-316 (UPDATED) has been reviewed and is approved for publication.

APPROVED: Kenneth R. Siarkiewicz

KENNETH R. SIARKIEWICZ
Project Engineer

FOR THE COMMANDER: John J. Bart

JOHN J. BART, Chief Scientist
Reliability Sciences
Electromagnetics & Reliability Directorate

If your address has changed or if you wish to be removed from the Rome Laboratory mailing list, or if the addressee is no longer employed by your organization, please notify RL (ERST) Griffiss AFB NY 13441. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document require that it be returned.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1994	Final Jan 93 - Jul 93

4. TITLE AND SUBTITLE
GRAPHICAL AIDS FOR THE USERS OF GEMACS (GAUGE): RAY TRACING ENHANCEMENTS

5. FUNDING NUMBERS
C - F30602-93-C-0022
PE - 64256F
PR - 3321
TA - 03
WU - P2

6. AUTHOR(S)
Jeffrey A. Evans and Edgar L. Coffey

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Decision-Science Applications, Inc.
1110 N. Glebe Road
Suite 400
Arlington VA 22201

8. PERFORMING ORGANIZATION REPORT NUMBER
DSA Report #105/1460

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Rome Laboratory (ERST)
525 Brooks Road
Griffiss AFB NY 13441-4505

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
RL-TR-88-316, Updated

11. SUPPLEMENTARY NOTES
Rome Laboratory Project Engineer: Kenneth R. Siarkiewicz/ERST/(315) 330-2465

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report contains update pages for RADC-TR-88-316, same title. The capability to plot rays from source points to observation points via multiple scattering centers has been added to the original suite of operations available in the original GAUGE package. This is useful for antenna design and system integration studies.

DTIC [illegible]

14. SUBJECT TERMS
GEMACS, Modeling & Simulation, Graphics, Uniform Theory of Diffraction (UTD), Geometric Theory of Diffraction (GTD)

15. NUMBER OF PAGES
32

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Table of Contents

Table of Contents

Table of Contents

Section **Page**

Table of Contents

Section **Page**

Section Page

Section Page

Table of Contents

List of Figures

List of Figures

List of Figures

List of Figures

This page intentionally left blank

C.4.5 RAY PATH VISUALIZATION

The primary method for visualizing computational electromagnetic (CEM) analysis data is to plot in 2 or 3 dimensions the radiation patterns generated. During this effort a new method of viewing the data was devised and implemented in GEMACS and GAUGE. GEMACS calculates the path the EM radiation will follow from a source to a requested field point. For this effort this path information was written off to an auxiliary file. This data is then displayed on the geometry via the CAD program GAUGE. This method of displaying path information on geometry has been used successfully in the computational fluid dynamics (CFD) field and shows great promise for CEM.

The syntax of the ray path command in GEMACS is given as follows:

RAYPTH [ON][OFF] LU=unit#
where: unit# > NUMFIL

The RAYPTH ON and OFF commands must bracket the GEMACS EFIELD command(s) for which the user wants ray paths generated. That is the RAYPATH ON command must be placed before the EFIELD command(s) and the RAYPATH OFF command must be placed after the EFIELD command(s).

The remainder of this section will describe how to use the ray path plotting capabilities of GAUGE. The figures in this section are screen snapshots taken in standard VGA mode. The normal screen background is black but it has been changed from black to white for this document

C.4.5.1 RAY PATH PLOTTING

The GAUGE Graphical Processor (GAUGEGP) provides the ray plotting capabilities via the post processor menu as shown in the following figure (option Y).

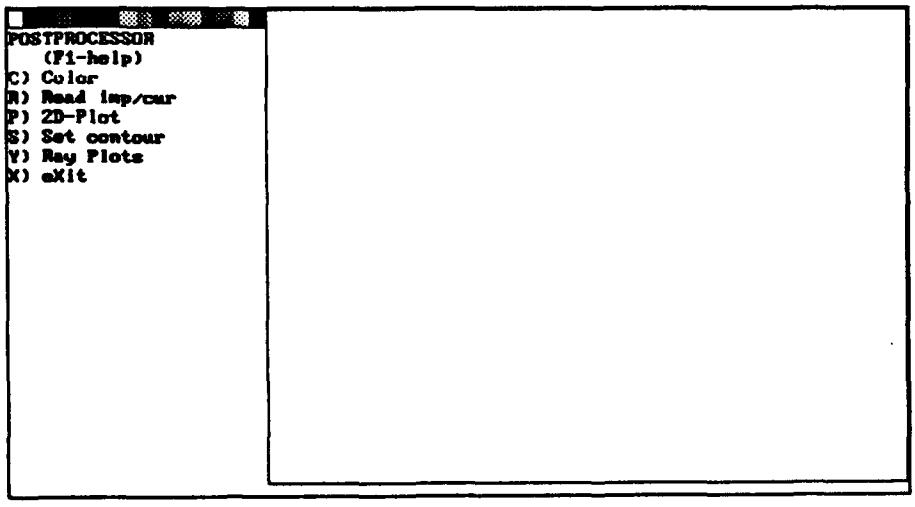

Figure C.4.10. GAUGEGP Post Processing Menu

When the *Ray Plots* option is chosen from the post processor menu, the RAY PLOTTING menu shown below is displayed. It should be noted that a geometry must be read before access to the RAY PLOTTING menu is granted. All of the ray path reading, plotting and labeling is performed from this menu.

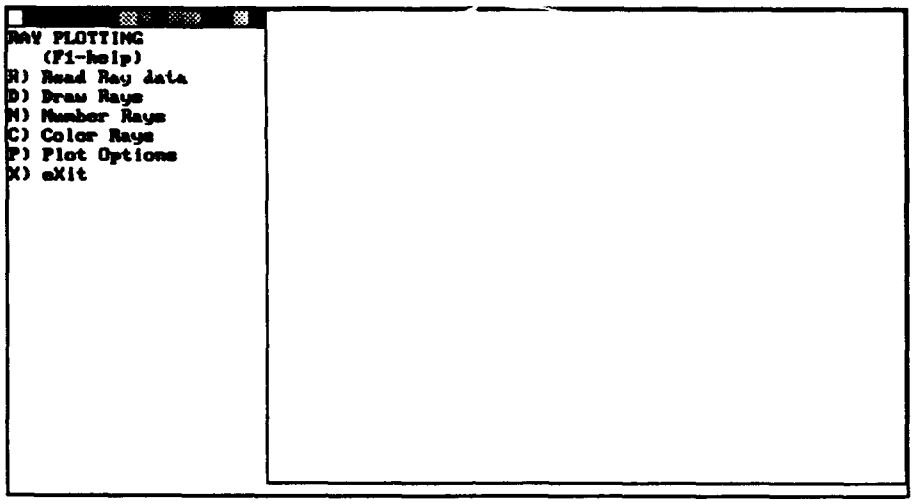

Figure C.4.11. Ray Trace Menu

C.4.5.1.1 Read Ray Data

Selecting the *Read Ray Data* item from the Ray Plotting menu brings up a standard GAUGEGP file selection menu utilized to browse for ray path data files (The ray path filenames should be of the form *.RAY). After a ray path data file has been selected and the *ACCEPT* (F9) item has been selected, the data is read into a GAUGEGP data structure for subsequent plotting on the screen. The Read Rays menu is shown in the following figure.

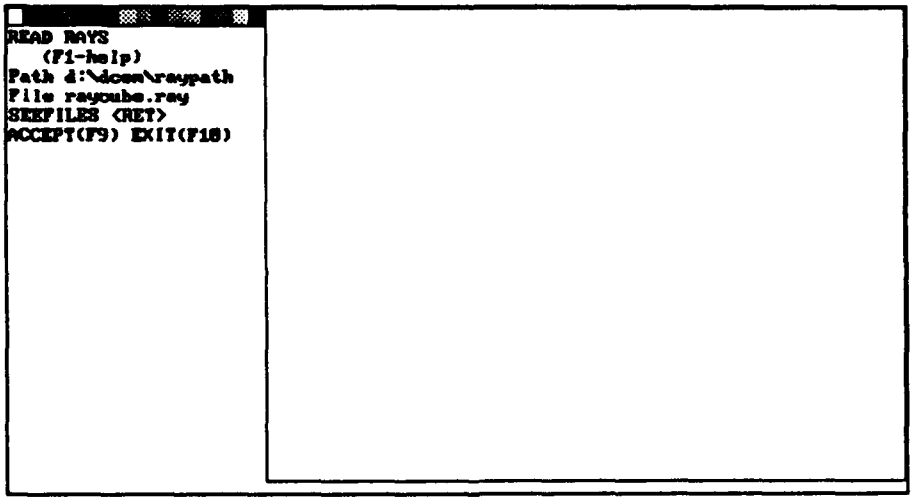

Figure C.4.12. Read Rays Menu

The format of the ray path data file that is generated is given in the following figure.

Comment	Line	Description				Example			
Control Line	1	NumRays	Mag.	Source Switch	Field Switch	2	2.3	1.0	0.0
Data Points	2	x_1 y_1 z_1		x_2 y_2 z_2		1.0 0.0 0.0		-0.5 0.5 -1.0	
	...	...		...		...		...	
	m = 2 + NumRays	x_{n-1} y_{n-1} z_{n-1}		x_n y_n z_n		-0.5 0.5 -1.0		1.0 0.0 0.0	
Control Line	m+1	NumRays	Mag	Source Switch	Field Switch	2	2.3	1.0	0.0
Data Points	m+2	x_1 y_1 z_1		x_2 y_2 z_2		1.0 0.0 0.0		0.5 0.5 0.0	
	...	...		...		...		...	
	m=m+2+ NumRays	x_{n-1} y_{n-1} z_{n-1}		x_n y_n z_n		0.5 0.5 0.0		1.0 0.0 0.0	
Control Line	last	NumRays	Mag.	Source Switch	Field Switch	-1	0	0	0

Figure C.4.13. Ray Path File Format

The data file consists of the set of ray paths that were generated by a combination of the GEMACS RAYPTH and EFIELD commands. Each ray path set of data points is preceded by a control line. The *NumRays* entry on the control line gives how many ray segments make up the total ray path. The next value, *mag*, is the magnitude of the ray path. The *Source Switch* and *Field Switch* values tell whether the ray path source and field points are in the near field (1) or the far field (0) with respect to the global origin. The near field (x, y, z)–tuple are actual cartesian coordinates of the end of the ray segment whereas the far field (x, y, z)–tuple is the unit direction vector for that location. In the case of a far field *Field Switch* a unit the last (x, y, z)–tuple in the list represents a pointing direction from the previous (x, y, z)–tuple. For a far field source switch the first (x, y, z)–tuple is a unit vector pointing to the next (x, y, z)–tuple in the list. The switches only apply to the first (source switch) and last (field switch) (x, y, z)–tuples in the ray path. The last line of the data file is a control line with a -1 as the number of path segments. Complete listings of the GTD Plate model of a cube and its associated ray path data file are shown below.

Cube GEMACS Input Data File: RAYCUBE.GEM

```
$
$  GTD Plate model of a Cube test problem for GEMACS
$  Ray Path printing
$
$  Illustrates the RAYPTH (Ray Path) command
$
DISPLA ON LU=0
NUMFIL=17
FRQ=1000.0
SETINT PL EI ORDER=0,1
GMDATA=BOX
SRC=ESRC(BOX) DW=1.,0. R=5. THETA=70. PHI=0. ECC=0.0
$
RAYPTH ON LU=99
$
FLD=EFIELD(BOX)  T1=110.  P1=0.
```

```
$
RAYPTH OFF
$
END OF COMMANDS
$
$ Created by GAUGE Ver. 1.4
$ Decision-Science Applications
$
PT     1          1.0000          1.0000         -1.0000
PT     2          1.0000          1.0000          1.0000
PT     3          1.0000         -1.0000         -1.0000
PT     4          1.0000         -1.0000          1.0000
PL     1    4     3     1     2     4
$
END of Geometry
```

Cube Ray Path Data File: RAYCUBE.RAY

This file was generated by GEMACS as FOR099.USR and was manually renamed RAYCUBE.RAY.

```
   1   4.8891490E+00   1.00   1.00
3.53553E+00  0.00000E+00  3.53553E+00    5.00000E+00  0.00000E+00 -2.18557E-07
   2   1.9945090E-02   1.00   1.00
3.53553E+00  0.00000E+00  3.53553E+00    1.00000E+00  1.00000E+00 -1.00000E+00
1.00000E+00  1.00000E+00 -1.00000E+00    5.00000E+00  0.00000E+00 -2.18557E-07
   2   4.6291230E-02   1.00   1.00
3.53553E+00  0.00000E+00  3.53553E+00    1.00000E+00  1.00000E+00  1.00000E+00
1.00000E+00  1.00000E+00  1.00000E+00    5.00000E+00  0.00000E+00 -2.18557E-07
   2   1.9945110E-02   1.00   1.00
3.53553E+00  0.00000E+00  3.53553E+00    1.00000E+00 -1.00000E+00 -1.00000E+00
1.00000E+00 -1.00000E+00 -1.00000E+00    5.00000E+00  0.00000E+00 -2.18557E-07
   2   4.6291110E-02   1.00   1.00
3.53553E+00  0.00000E+00  3.53553E+00    1.00000E+00 -1.00000E+00  1.00000E+00
1.00000E+00 -1.00000E+00  1.00000E+00    5.00000E+00  0.00000E+00 -2.18557E-07
   2   1.6739670E-01   1.00   1.00
3.53553E+00  0.00000E+00  3.53553E+00    1.00000E+00 -3.04886E-07 -1.00000E+00
1.00000E+00 -3.04886E-07 -1.00000E+00    5.00000E+00  0.00000E+00 -2.18557E-07
   2   4.9815790E-01   1.00   1.00
3.53553E+00  0.00000E+00  3.53553E+00    1.00000E+00 -2.93869E-07  1.00000E+00
1.00000E+00 -2.93869E-07  1.00000E+00    5.00000E+00  0.00000E+00 -2.18557E-07
  -1   0.0000000E+00    .00    .00
```

C.4.5.1.2 Draw Rays

The *Draw Rays* menu item toggles the actual drawing of the ray paths in the GAUGEGP drawing windows. The following figure shows a plot of the ray paths bouncing off of a simple plate model of a cube.

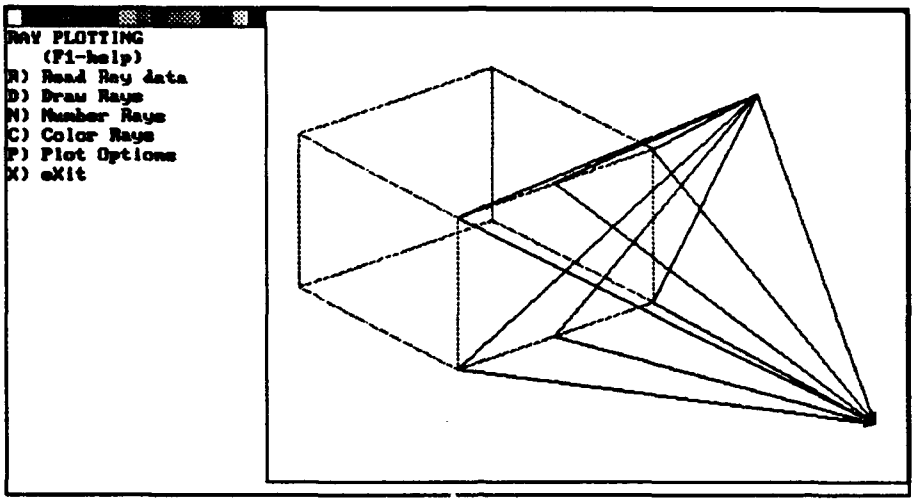

Figure C.4.14. Ray Plot of Cube

C.4.5.1.3 Number Rays

The actual ray paths in the data file do not have an identification number, but for the GAUGE ray tracing process they are numbered based on the order they were read from the data file. The *Number Rays* menu item places the id number on each segment of the ray paths that are plotted as shown in the following figure.

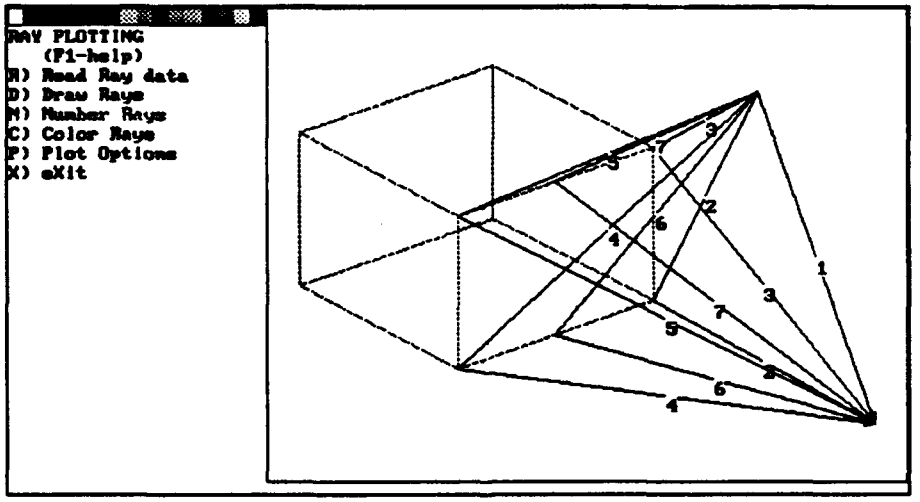

Figure C.4.15. Numbered Rays on the Cube

C.4.5.1.4 Color Rays

The *Color Rays* menu item sets the color of each ray based upon the magnitudes of the ray paths that were read. The colors are generated based upon a linear division of the magnitude values. The following figure illustrates the use of the *Color Rays* option. For this report the

colors of the ray paths are represented by different line styles. The solid line represents direct paths. The dashed line styles are proportional to the magnitude of the ray path.

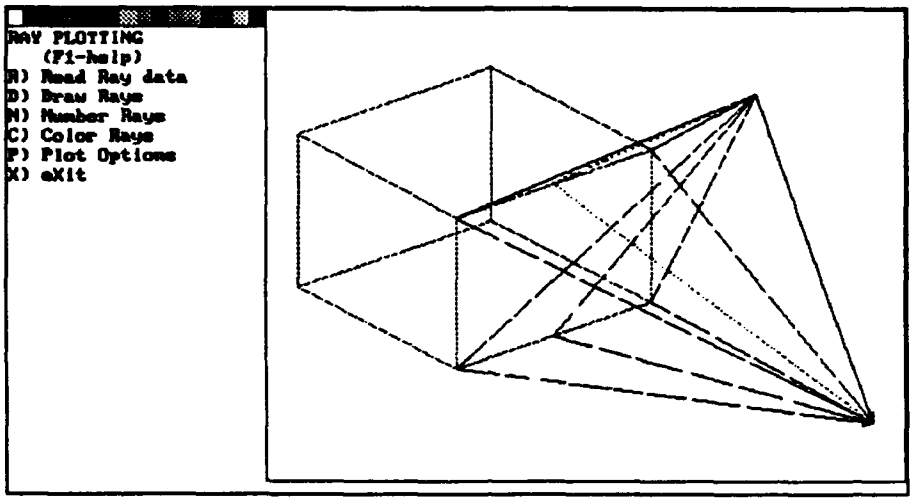

Figure C.4.16. Colored Rays on the Cube

C.4.5.1.5 Ray Plotting Options

The *Plot Options* menu item brings up a submenu that provides three different methods for plotting a subset of the ray paths. The following figure shows the RAY SHOW menu. Once a set of rays has been selected, then the user has the option to show only those rays, no-show only those rays, adding those rays to show or adding those rays to the no-show similar to the geometry show/no-show capability of GAUGEGP. A separate RAY SHOW MODE menu shown in Figure C.4.18 will be displayed after the ray path selection(s) has been made.

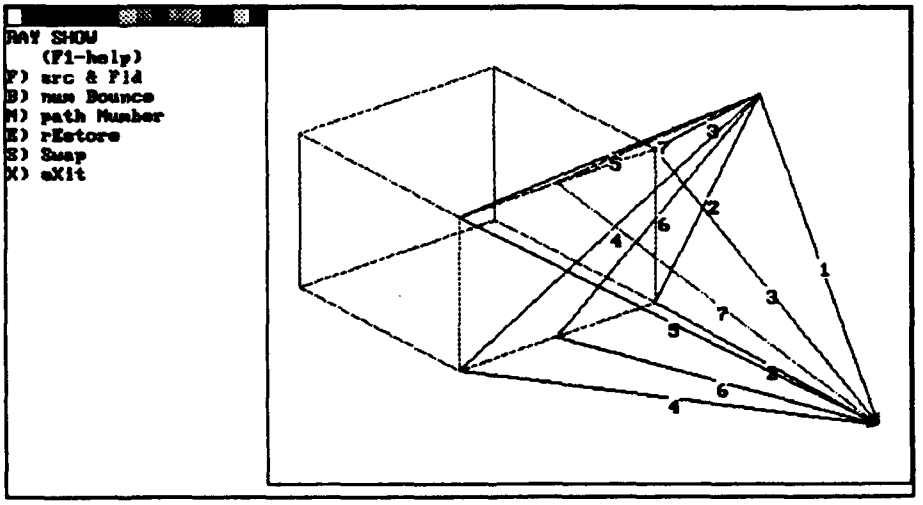

Figure C.4.17. Ray Plotting Options

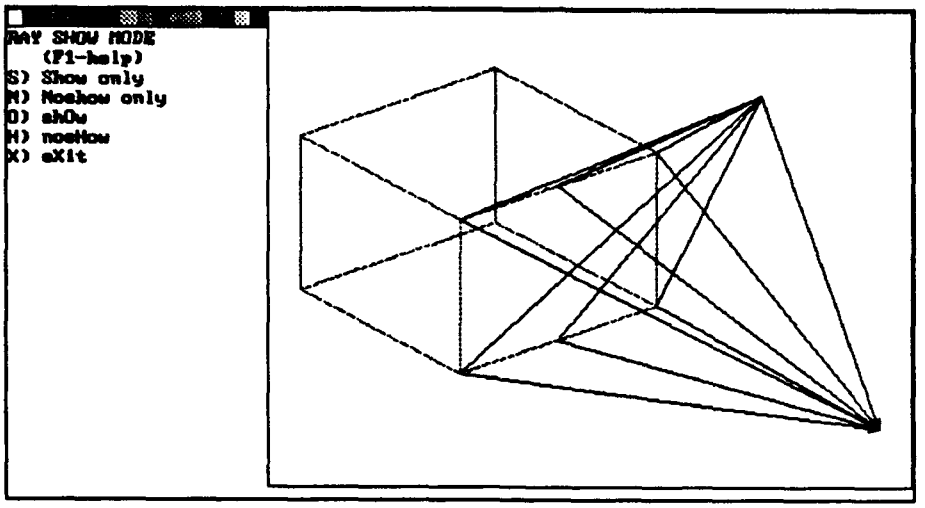

Figure C.4.18. Ray Show Mode Options

C.4.5.1.5.1 Source & Field

The first method of selecting a subset of ray paths to plot is by their source and field points. The following figure shows the menu used to select the source and field values to use. A range of values can be typed into each area corresponding to the n^{th} source or field point. If the numbers are left as 0, then all of the sources or fields are used. The selection of the paths to plot is based on ANDing the source locations selected with the field locations selected. If a ray path meets the condition of having its source in the selected source list and its field in the selected field list, then it is added to the selected paths list. This list is then used for showing or noshowing the rays.

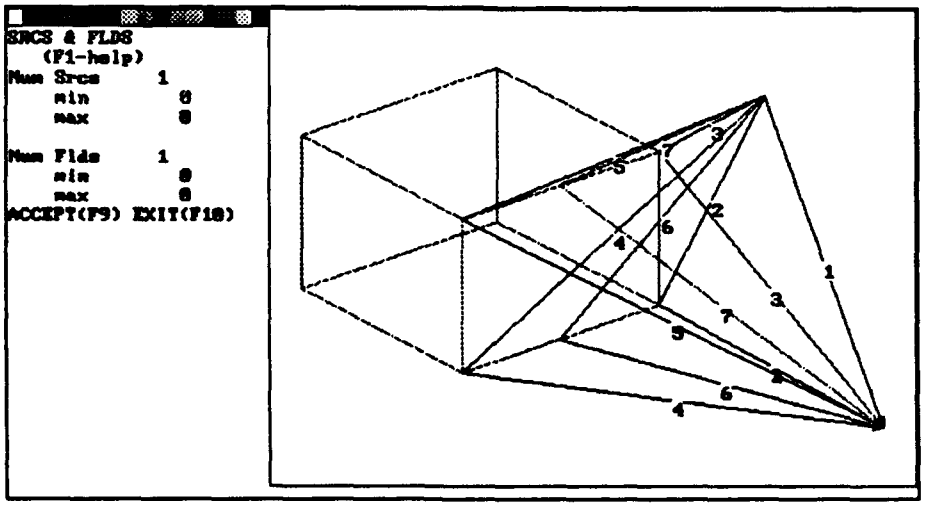

Figure C.4.19. Ray Selection by Source & Field Dialog Box

C.4.5.1.5.2 Number of Bounces

The second selection method is by the number of bounces in a ray path. The *num Bounce* method is shown in the following menu. Direct rays, from the source point(s) to the field point(s), are selected by the top toggle menu item. A carriage return toggles the menu item between OFF and ON. When a number is entered in the lower field only, those rays with that number of bounces will be selected. A zero bounce ray is equivalent to direct rays.

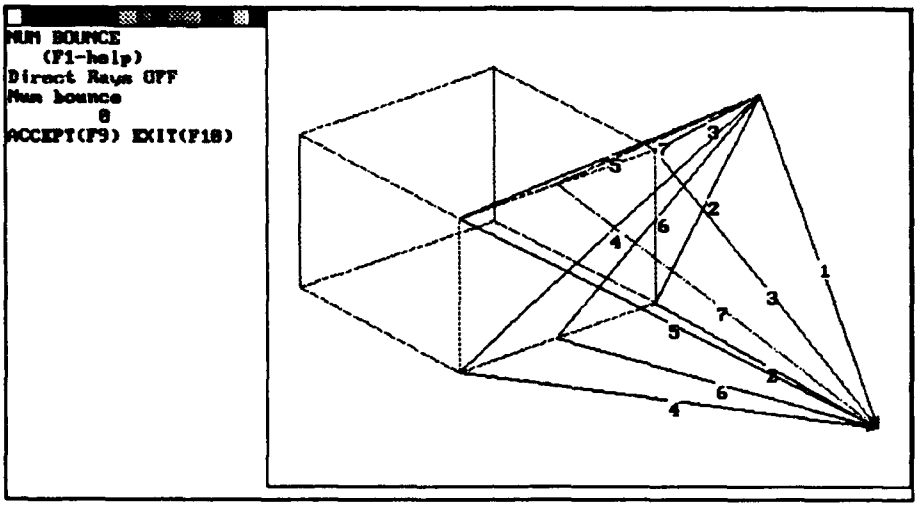

Figure C.4.20. Ray Selection by Number of Bounces Dialog Box

C.4.5.1.5.3 Path Number

The last selection method is by the number of the ray path. The BY PATH NUM menu provides for selecting the ray paths by the order they were read into the database. This menu is shown in Figure C.4.21. Direct rays for a given field pattern are stored first with all higher order rays for that field coming after the direct rays. This menu should be used in conjunction with the numbering of the rays on the screen (see Section C.4.5.1.3) to narrow the selection of ray paths. The menu can accept 3 ranges of path numbers. If a range is left blank or filled with zeros, it is not considered. Both the *Num Min* and *Max* entries of the range must be entered correctly to select the ray paths. Only those rays that fall within the number range will be selected.

C.4.5.1.5.4 Restore

A ray path data set that has been partitioned by the ray show/no-show option may be restored to the original state of showing all ray paths using this menu item. This option restores all ray paths in memory to show status.

C.4.5.1.5.5 Swap

A portion of the ray paths that has been assigned the show status may be changed to the no-show status and vice versa.

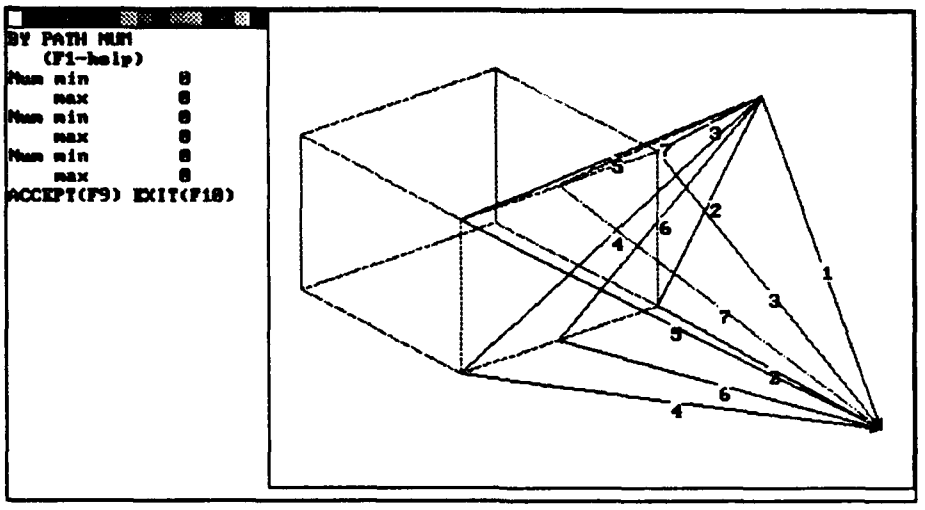

Figure C.4.21. Ray Selection by Path Number Dialog Box

C.4.5.2 RAY PATHS ON CYLINDER EXAMPLE

The next pair of figures shows an example of using GEMACS to calculate the scattering from a GTD cylinder. There is one source point and one field point. The left figure shows all the ray paths that were calculated from the source to the field. The right figure shows a top view of the detail on ray paths 3 and 4. These two paths illustrate the ray creeping around the cylinder. Ray path 3 creeps around a small quadrant (<45 degrees), while ray path 4 goes all the way around the cylinder before it detaches and proceeds to the field point.

It is straightforward to verify that ray path 3 only traverses a small quadrant of the cylinder. First, the magnitude of ray path 3 is only slightly less than the magnitude of ray path 2 which has a single bounce off the cylinder. Second, the magnitude of ray path 4 is much less than that of ray path 3, and it can be concluded that ray path 4 traverses the entire geometry in the figure. Third, any waves that traverse more that 2π degrees around the cylinder are excluded by GEMACS because these waves are greatly attenuated.

This ability of the ray path plotting can be used to visualize the coupling between antennas on opposite sides of a fuselage for example. The GEMACS input and ray path listings for the cylinder example are given following Figures C.4.22 and C.4.23.

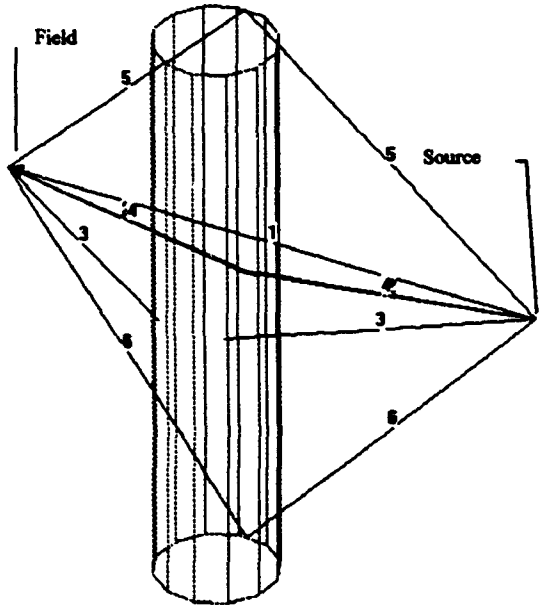

Figure C.4.22. Ray Paths on a GTD Cylinder

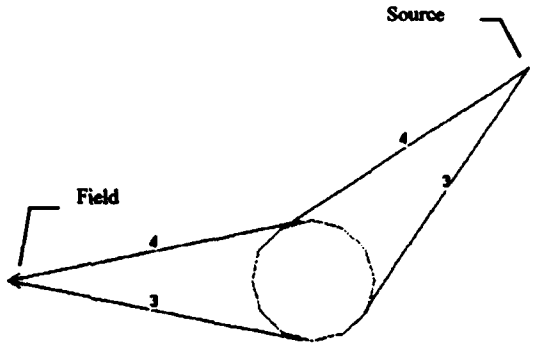

Figure C.4.23. Creeping Waves on a GTD Cylinder

Cylinder GEMACS Input Data File: RAYCYL.GEM

```
$
$  Cylinder test problem
$
$  Illustrates the RAYPTH (Ray Path) command
$
DISPLA ON LU=0
NUMFIL=17
FRQ=1000.0
SETINT PL EI ORDER=0-3
GMDATA=CYLIN
SRC=ESRC(CYLIN) DW=1.,0. R=5. THETA=90. PHI=0. ECC=0.0
RAYPTH ON LU=99
FLD=EFIELD(CYLIN)  T1=90.  P1=180.  R1=5.
RAYPTH OFF
$
END OF COMMANDS
$
$
CY  1  1.  1.  10.  0
EC  1  1   0.   0.
EC  2  -1  180.  0.
$
END of Geometry
```

Cylinder Ray Path Data File: RAYCYL01.RAY

This file was generated by GEMACS as FOR099.USR and was manually renamed RAYCYL01.RAY.

```
    1   2.4453194E+00    1.00    1.00
 3.53553E+00  3.53553E+00 -2.18557E-07   -5.00000E+00 -4.37114E-07 -2.18557E-07
    2   6.3531101E-01    1.00    1.00
 3.53553E+00  3.53553E+00 -2.18557E-07   -3.82683E-01  9.23880E-01 -2.18557E-07
-3.82683E-01  9.23880E-01 -2.18557E-07   -5.00000E+00 -4.37114E-07 -2.18557E-07
    2   1.7755465E-01    1.00    1.00
 3.53553E+00  3.53553E+00 -2.18557E-07    8.34242E-01 -5.51399E-01 -2.18557E-07
-2.00000E-01 -9.79796E-01 -2.18557E-07   -5.00000E+00 -4.37114E-07 -2.18557E-07
    2   2.2705419E-05    1.00    1.00
 3.53553E+00  3.53553E+00 -2.18557E-07   -5.51399E-01  8.34242E-01 -2.18557E-07
-2.00000E-01  9.79796E-01 -2.18557E-07   -5.00000E+00 -4.37114E-07 -2.18557E-07
    2   3.8389534E-02    1.00    1.00
 3.53553E+00  3.53553E+00 -2.18557E-07   -3.82684E-01  9.23880E-01  5.00000E+00
-3.82684E-01  9.23880E-01  5.00000E+00   -5.00000E+00 -4.37114E-07 -2.18557E-07
    2   4.6092547E-02    1.00    1.00
 3.53553E+00  3.53553E+00 -2.18557E-07   -3.82684E-01  9.23879E-01 -5.00000E+00
-3.82684E-01  9.23879E-01 -5.00000E+00   -5.00000E+00 -4.37114E-07 -2.18557E-07
   -1   0.0000000E+00    0.00    0.00
```

MISSION

OF

ROME LABORATORY

Mission. The mission of Rome Laboratory is to advance the science and technologies of command, control, communications and intelligence and to transition them into systems to meet customer needs. To achieve this, Rome Lab:

a. Conducts vigorous research, development and test programs in all applicable technologies;

b. Transitions technology to current and future systems to improve operational capability, readiness, and supportability;

c. Provides a full range of technical support to Air Force Materiel Command product centers and other Air Force organizations;

d. Promotes transfer of technology to the private sector;

e. Maintains leading edge technological expertise in the areas of surveillance, communications, command and control, intelligence, reliability science, electro-magnetic technology, photonics, signal processing, and computational science.

The thrust areas of technical competence include: Surveillance, Communications, Command and Control, Intelligence, Signal Processing, Computer Science and Technology, Electromagnetic Technology, Photonics and Reliability Sciences.